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Viability of solar or wind for water pumping systems in the Algerian Sahara regions – case study Adrar

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A R T I C L E I N F O

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A B S T R A C T

The availability of water and the ability to access are the key questions arising in developing countries including Algeria. Indeed, due to lack of electricity, the Saharan regions representing 80% of the country are facing major problems to cover drinking water needs. Paradoxically, there is in some of these areas an important quantity of groundwater at shallow depths. On the other hand, Algeria has considerable renewable energy resources, particularly solar and wind energy options that are now relevant solutions to this problem. To date, few facilities specifically photovoltaic were conducted throughout the national territory (Saharan regions and highlands). However vandalism (destruction, robbery, etc.) did not spare these facilities particularly in border areas, such Adrar, and therefore prospective purchasers of such systems are discouraged. A new strategy to deal these actions became necessary for the regions most affected.

In this context, we propose to study and compare the two options for solar and wind water pumping applications in the Adrar region. Because it has become necessary that the energy issue arises in new terms. It is proposed now to ask, taking into account the circumstances, which form of energy would be appropriate for what and for which ends. In other words, we will essentially develop a new spirit, a new attitude that would be based on a determination on a case by case basis, of the appropriate energy resource. This will allow to have another vision of the use and the viability of renewable energies.

Contents

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1. Introduction

The water availability and the ability to access to it are the key issues facing the community in the world especially in developing countries. Algeria's Saharan regions which cover more than 80% of its area (2,381,741 km^2), is also affected and suffers more from this thorny problem. Needs for domestic water supply, irrigation of crops and watering of animals increase with population growth. In the absence of surface water, groundwater aquifers seems to be the only alternative to this dilemma, but is difficult for manual pumping and animals. However, preservation of ecosystems in the Saharan regions can be achieved with the fixing of the population in their areas by means of improving and developing their standard of living and so curb a little the exodus to the urban centers. This socio-economic development of these regions is closely related to two main factors which are the presence of water and energy availability.

Mechanized water pumping has become the only reliable alternative to lift water at a certain depth. Diesel and gasoline have traditionally been used to pump water in these regions. Their use requires a large volume of fuel when available. Using this type of system cause the discharge gases to the atmosphere, increases the level of pollution and nuisance to the environment and also pollution of groundwater and soil by fuel and lubricants.

On the other hand, renewable energy can provide alternative energy quite realistic due to their low environmental impact. Among the various identifiable sources of renewable energy in Algeria, two attract attention in this study for their important potential areas of applications: they are photovoltaic (PV) and wind energies [1–3].

The solar and wind water pumping systems are reliable, now emerging on the market and quickly become more attractive than conventional energy sources are particularly useful in remote locations where a regular fuel supply is problematic.

In the search for solutions to the energy management practices applicable to pumping irrigation schemes in the Sahara, it seems interesting to identify the most appropriate technology, taking into account the specificities of the region (solar or wind) and know the benefits of pumping technique based on the reliability of two renewable sources, namely solar photovoltaic and wind energy under certain conditions.

In the absence of surface water, groundwater is an important source for drinking and irrigation in these regions. In addition, the majority of these regions constituting the Sahara has an important groundwater resource, namely the Albian water which outcrops in some places. Fig. 1 shows the extent of the groundwater in Algeria, occupying the southeast and much of south-western Sahara.

Formations of continental clastic infill constitute a large reservoir of 600,000 km^2 [4]. In Algeria, it is located in the northern Sahara and extends to Tunisia and Libya. This reservoir is flush with the south it is semi free captive in the west and its eastern part [4,5].

In the absence of reliable means of drainage, renewable energies are the most appropriate solution to meet the energy needs of the population. However the acts of vandalism (robbery of PV modules) perpetrated in the isolated areas undermine the longevity and the use on large scale of these systems, more particularly the PV systems.

2. Potential energy of Adrar

Located in the southwest of Algeria (27°52′N, 0°17′W), Adrar occupies an area of 427,368 km^2, a population of 422,331 inhabitants (National Office of the Statistics-Algeria, 2010) with very low population density estimated at 0.98 inhabitants/km^2 (National Office of the Statistics-Algeria, 2010). Agriculture, traditional crafts

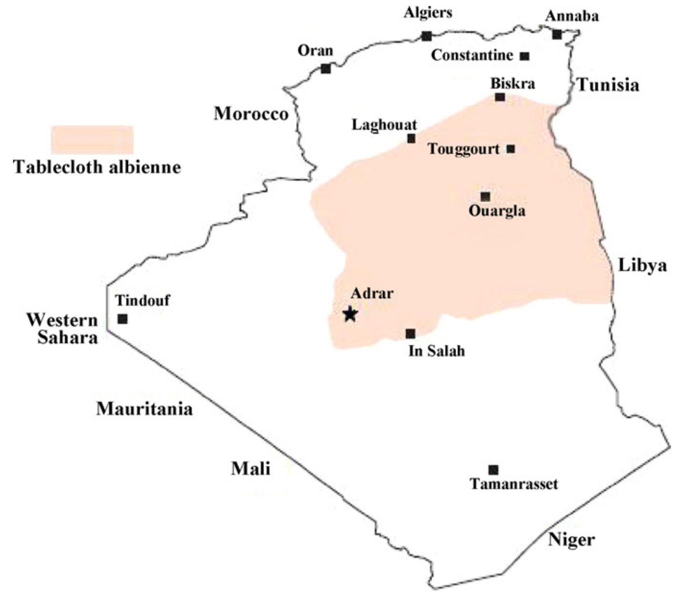

Fig. 1. The tablecloth albienne covers all Algerian central Sahara until Libya [4].

as well as barter trade with neighboring countries (Mali, Niger), form the backbone of the economy of the region. Due to the very low standard of living, the majority of the population practices mainly subsistence farming. The rest of agricultural production is sold in the markets. The huge availability of groundwater at shallow depths in some places, easy to operate, means that agriculture could be developed on a large scale with moderate electrical power.

So the strengths of the Adrar region are mainly related to agricultural, phoeniculture (palm plantation) and other agricultural products, with the potential irrigable land is very important and the potential use of solar and wind according to the viability, and finally there is a huge aquifer of the groundwater.

The Adrar region has a pool solar and wind very significant. The operation of these inexhaustible energy resources can meet the energy needs of the population. The majority of villages in the wilaya (department) constituting Adrar could be considered as isolated sites due to the huge size and their distance from each other in addition to climatic conditions which are extremely difficult.

2.1. Solar energy

Algeria has a high solar potential and is adequate for the use of solar energy systems, particularly in southern regions (Sahara region). Based on data from the hourly global irradiation on horizontal surface, we can see from Fig. 2 that the Adrar region has a higher average annual daily to 5.7 kWh/m^2/day. Fig. 2 also shows the average monthly temperatures.

Fig. 2 shows that the winter has less solar potential whose average daily monthly global radiation varies between 3 kWh/m^2/day and 4 kWh/m^2/day. Solar radiation becomes very important between March and October when the average daily monthly global radiation varies from 5.5 kWh/m^2/day to 7.5 kWh/m^2/day. Fig. 3 shows the importance of global irradiation in terms of hourly PV array with a tilt angle equal to the latitude of Adrar relative to the hourly global irradiation on horizontal plane, where the values vary between 600 and 1000 Wh/m^2 for the month of January.

2.2. Wind energy

To assess the operating performance of a wind turbine at a given location, its energy production is first expressed in terms of wind speed. Among the many mathematical models used in studies of

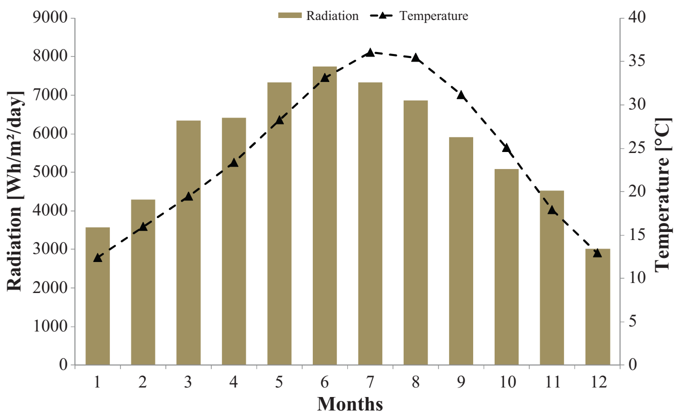

Fig. 2. Average daily monthly irradiance and temperature of Adrar.

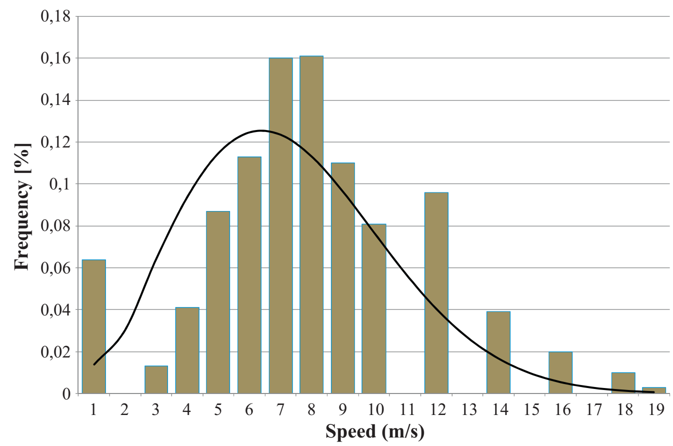

Fig. 4. Distribution of wind speed in site Adrar.

wind power, the cumulative Weibull statistical distribution is most appropriate to describe the variations in wind speed. It is given by [6,7]:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left(-\left(\frac{v}{c}\right)^{k}\right) \quad (1)$$

where $f(v)$ is the Weibull probability density function; k is the dimensionless shape factor which describes the distribution of the wind; c is the scale factor (m/s) which characterizes the wind speed; v is the average wind speed (m/s).

Fig. 4 shows the wind speed distribution of Adrar [8]. By studying the distribution of this speed, we can notice that:

- 20.5% of wind speeds are less than or equal to 4 m/s,
- 62.5% of wind speeds between 5 and 9 m/s (representing the right speed for low power turbines),
- 17% of wind speeds above 10 m/s (nominal speed of most wind turbines of average power).

In view of these surveys to measure wind speed, we can notice that the Adrar region, could be a region favorable to the exploitation of wind energy small systems.

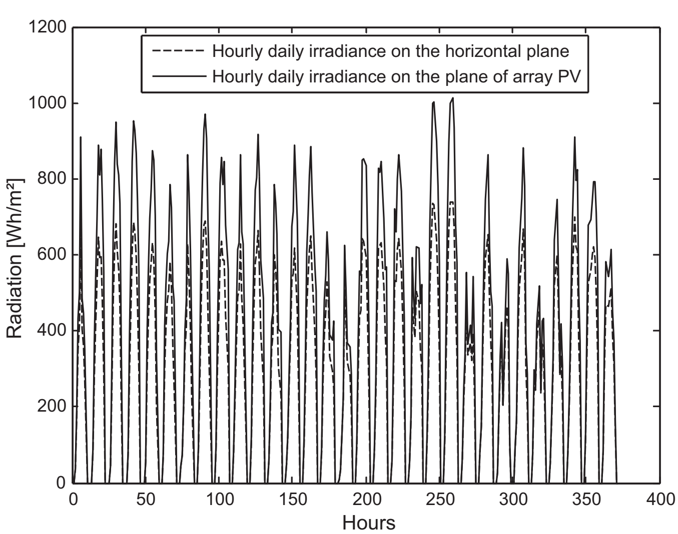

Fig. 3. Hourly global radiation on the horizontal and array PV plane (angle of inclination equal to the latitude of the site) – January – Adrar.

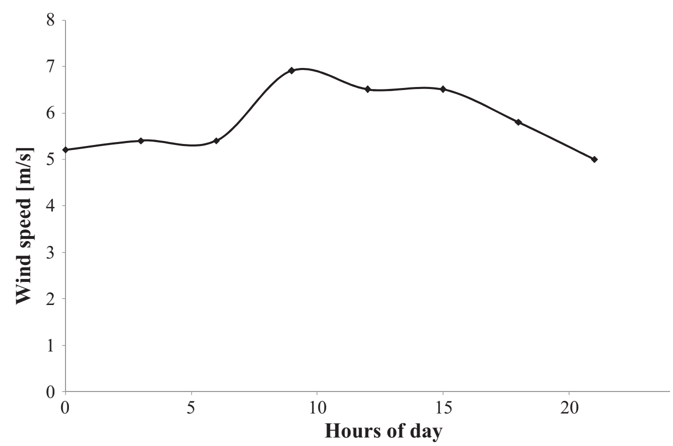

Fig. 5. Variation of average speed tri annual hourly wind site of Adrar.

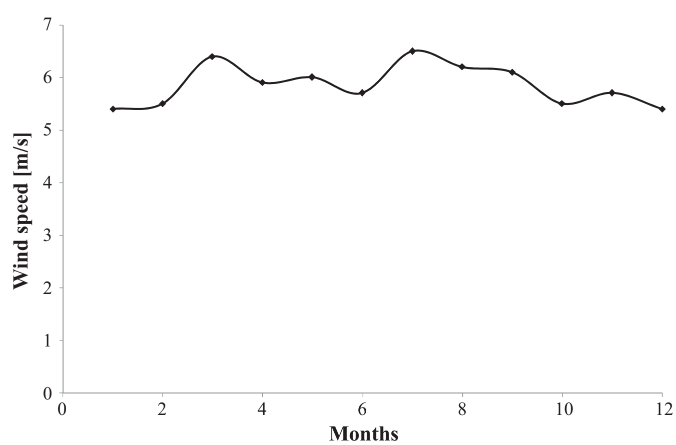

Fig. 6. Wind speed average monthly site of Adrar.

2.2.1. *Study of the variation of wind speed*

Based on data published in the Wind Atlas of Algeria established by the National Office of Meteorology [8], average speeds tri-annual hourly schedule and mean monthly wind speeds for the site Adrar are represented in Figs. 5 and 6.

Fig. 5 shows the variation of average speed tri-annual hourly wind site of Adrar, which has a relatively large potential wind whose speed is greater than or equal to 5 m/s throughout the day. Fig. 6 shows that the site Adrar has an average speed almost constant during the year.

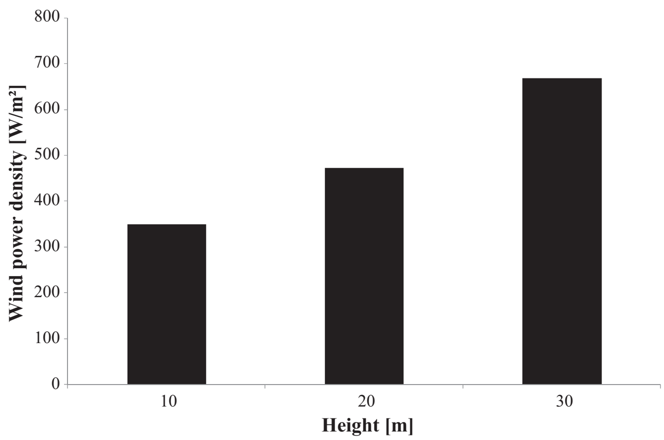

Fig. 7. Wind power density for different heights (10 m, 20 m and 30 m).

2.2.2. Wind power density

Assuming that the air density (ρ_{air}) constant, the average wind power density available is given by [9,10]:

$$\bar{P}_d = \frac{1}{2}\rho_{\text{air}}\bar{v}^3 \tag{2}$$

$$\bar{v}^3 = \sum_{i=1}^{N} f_i v_i^3 \tag{3}$$

where N is the number of measurements, v_i is the wind speed and $\bar{v}$ is the mean wind speed.

$$\bar{P}_d = \frac{1}{2}\rho_{\text{air}}\sum_{i=1}^{N} f_i v_i^3 \tag{4}$$

2.2.3. Wind speed extrapolation

The available wind data are results of measurements taken at 10 m above ground level. As wind speed increases with altitude [11–14], an empirical relationship is applied to extrapolate these data to the hub height. Its basic form is [11–14]:

$$\frac{v}{v_r} = \left(\frac{z}{z_r}\right)^{\alpha} \tag{5}$$

where v_r is the wind speed recorded at anemometer height z, v is the wind speed to be determined for the desired heights z, α is the power law exponent estimated using the wind speed measurement at the two altitudes, the value of 1/7 is usually taken [15].

Fig. 7 shows the wind power density available at Adrar. We notice a significant increase in power density as a function of hub height. On the site of Adrar, the density increases by 35% at 20 m and 90% at 30 m. Figs. 8 and 9 shows the variation of wind speed at the site of Adrar to two different heights 20 m and 30 m from the reference height of 10 m.In view of this study, the Adrar region could be a region favorable to the exploitation of wind energy small systems.

3. The sustainability of PV systems in the region of Adrar

To promote and popularize renewable energy systems, and through a government program aimed at different regions of the south, as the region of Adrar, Algeria has made free installation of more systems including autonomous photovoltaic (telecommunications, lighting, pumping, etc.) for the benefit of the population living in the Saharan regions. The majority of these installations have been made from the 90s by the Center for Development of Renewable Energies. Because of the low potential wind in Algeria, and given the inexperience of the researchers, all projects were geared only to the PV, while a source like wind power could also be implemented. Thus, the majority of these facilities were subject to acts of vandalism, destruction, robbery, bringing a blow to the development and wide use of this source of energy in these regions, particularly in the area of Adrar. Fig. 10 shows two photovoltaic pumping systems has delivered such acts where the entire system has been stolen, leaving only the mounting stakes of PV modules.

Considering that the wind system (wind turbine) could meet the needs of users with the same reliability, why not opt for this source of energy when the site is appropriate.

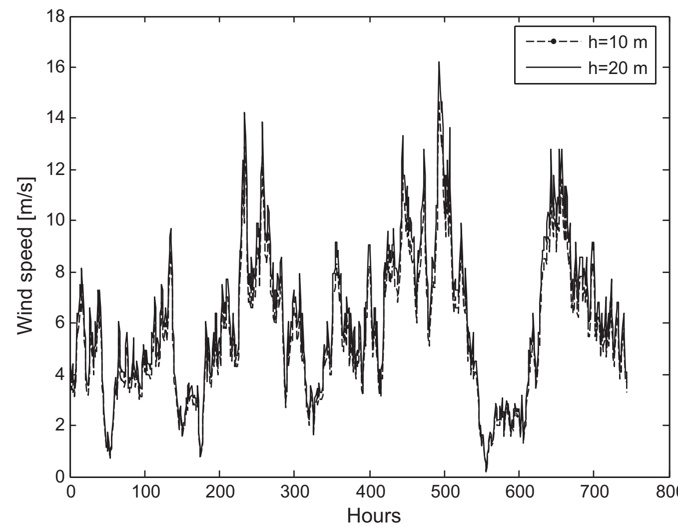

Fig. 8. Wind speed at different hub heights: 10 m and 20 m Adrar – January.

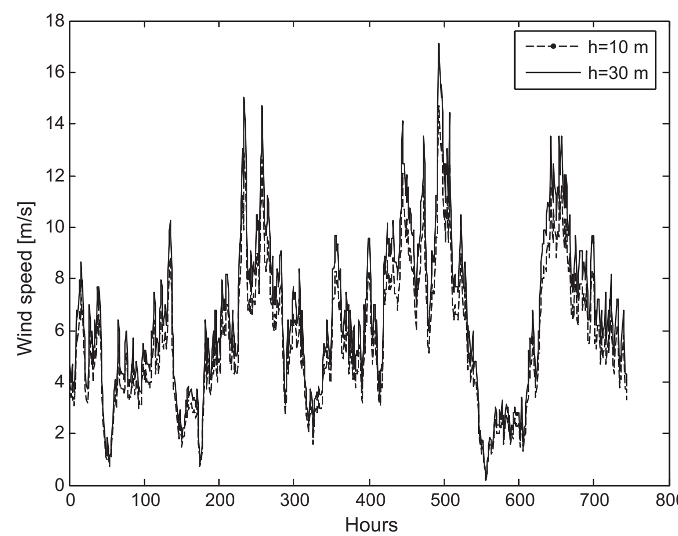

Fig. 9. Wind speed at different hub heights: 10 m and 30 m Adrar – January.

4. Economic study

The method of the LCC is most largely used to evaluate the financial viability of a system [16–20]. Economic attempts to study pumping PV systems in Algeria were carried out [21–23].

In Algeria, the use of the renewable energy is still at the beginning, in spite of the financing of several prototypes by the state. The major problems are certainly identified but very difficult to solve: high costs, customs taxes and especially the acts of vandalism have brought great harm to the photovoltaic solar energy systems.

Fig. 10. PV pumping engaged in acts of vandalism.

In what follows, we will try to evaluate the LCC of a PV pumping system compared to another source of replacement as motor-pump powered by wind system taking account some of these financial parameters. The life cycle cost of a pumping system can be calculated using the following equation:

$$LCC = C_{\text{inv}} + C_{\text{maint}} + C_{\text{remp}} \tag{6}$$

Financial expenses (C_{inv}), a system include the initial capital expenditure, design and installation of system. This cost is still considered payment occurring in the initial year of installing the system or by annuities. The maintenance costs (C_{maint}), is the sum of all costs annually scheduled. The replacement costs (C_{rempl}) is the sum of all costs of replacing equipment provided during the life cycle of the system occurs only in specific years.

4.1. Initial costs

The financial costs (C_{inv}) of a system include the initial capital expenditure for equipment, design and installation of the system. This cost is still considered payment occurring in the initial year of installing the system.

- *Pumping water PV system*

The main constituent components of a pumping water PV system are:

- An array consists of photovoltaic panels.
- An inverter DC/AC.
- A pump unit, whose characteristics depend on those of the water source.
- A structure for supporting the PV array.

- *Pumping water wind system*

Pumping water wind systems for usually consist of the same constituents as photovoltaic systems. We therefore find:

- A wind turbine, the height of the hub depends on the wind available in the installation site.
- A controller.
- An inverter DC/AC.
- A pump unit, whose characteristics depend on those of the water source.

4.1.1. Maintenance costs

Maintenance costs also some recurrent costs, are usually specified as a percentage of the cost of initial capital. All costs are subject to an annual inflation rate (e_0) and a discount rate (d). Maintenance costs are expressed by Eqs. (7) and (8) [24–27].

$$C_{\text{maint}} = M_0 \left(\frac{1+e_0}{d-e_0}\right)\left[1-\left(\frac{1+e_0}{1+d}\right)^{n_v}\right] \quad \text{if} \quad d \neq e_0 \tag{7}$$

$$C_{\text{maint}} = M_0 N \quad \text{if} \quad d = e_0 \tag{8}$$

M_0 is the operating and maintenance cost during the first year, n_v is the life of pumping system.

4.1.2. Replacement costs

The replacement cost of each component of the system is mainly based on the number of substitutions on the life cycle, its value is given by the following equation [24,27,28]:

$$C_{\text{remp}} = C_u \sum_{j=1}^{n} \left(\frac{1+e_1}{1+d}\right)^{((n_v j)/(n+1))} \tag{9}$$

where C_u is the unit cost of component replacement, e_1 is the inflation rate cost of replacement components, n is the number of replacing on the life cycle.

5. Results and discussion

5.1. Quantity of water produced by the PV and wind pumping systems selected

After calculating the optimal design of both photovoltaic and wind pumping systems studied, we represent in the following amount of water that could produce the two systems in question with a motor-pump unit selected on the basis of need and source characteristics water that, taking into account the variation of the performance of motor-pump unit according to the electrical power supplied by array PV or wind turbine. The height of the well is assumed to be constant.

Fig. 11 represents the amount of water produced by two motor-pump units (SP8A-10, SP14A-7 - Grundfos) for optimal configuration of array PV that meets the charge with a loss of power supply probability (LPSP) equal 0.01. We note that the system with the motor-pump unit SP8A-10 (rated capacity 8 m^3/h) can produce a quantity of water annually from 25,645 m^3. The system has a deficit during the month of December considered the worst month (very low daily radiation).

On the other hand, the amount of water that can be produced monthly with a wind turbine-type Fortis Montana 5000 W, using separately three motor-pump units, for the hub heights of 18 m and 24 m, and taking into account the variation of performance motor-pump unit with the power delivered by the wind turbine, is shown in Fig. 12.

By comparison to the needs, we notice that the wind system with the motor-pump unit SP8A-12 (nominal discharge 8 m^3/h) with a hub height of 18 m presents a significant surplus (33,386 m^3/year). The system with the motor-pump unit SP5A-12 (nominal discharge 5 m^3/h) and a hub height of 18 m presents a light deficit for December and January (24,922 m^3/year). On the

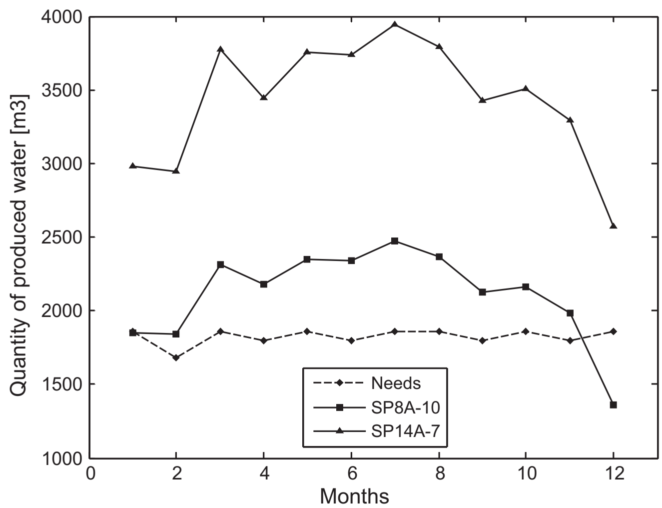

Fig. 11. Quantity of produced water by PV pumping system.

other hand the system with the motor-pump unit SP5A-12 and a hub height of 24 m does not record any deficit (26,335 m^3/year).

5.2. Economic analysis

The objective of this study is to make a cost comparison on two options; pumping PV system and pumping wind turbine system to install in the Adrar region and to define which of the two options is most viable.

The input parameters used for the economic evaluation are: the estimated costs of various components of the systems, the daily requirements, discount and inflation rates, the lifetime of PV and wind equipments, salvage values, costs of maintenance and operation and replacement costs of some subset. The analysis period is assumed to be 20 years at a discount rate of 10% and an inflation rate of 5% on the costs of maintenance and replacement of various equipment. Table 1 presents the technical and economics parameters used in the financial evaluation.

The cost of system installation (civil engineering, assembly structures, installation of the motor-pump unit inside the well, start, etc.) is assumed to be equal to 3% of the total cost of equipment. The maintenance and operation cost during the first year is

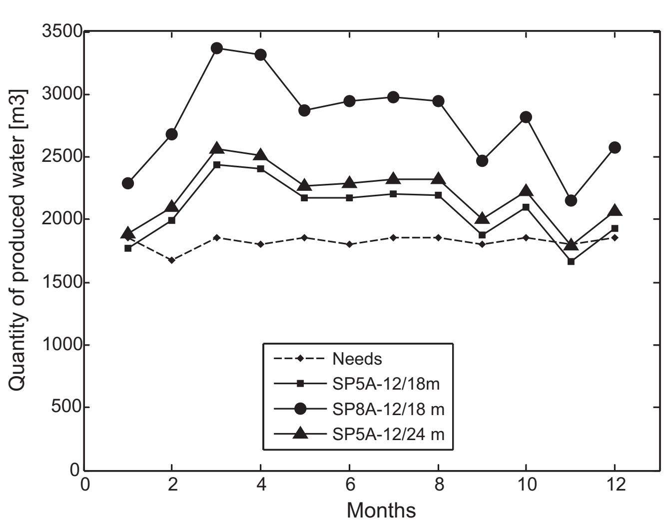

Fig. 12. Quantity of produced water by wind pumping system – wind turbine type: Fortis-montana 5000. Hub height: 18 m and 24 m – Adrar.

Table 1
Technical and economics parameters used in the financial evaluation.

Parameters	Symbol	Unit	Value
Head of pumping	h	m	45
Daily needs of water	Q	m^3	60
Efficiency of inverter DC/AC	η_{inv}		95%
Efficiency of unit submersible motor-pump	η_{mp}		40%
Power peak of PV module		W_c	120
Nominal power produced by wind turbine (Fortis-montana 5000)		W	5000
Hub height		m	18
Annual maintenance and operation costs as a fraction of the investment costs		Fraction	0.01
Discount rate	d	Fraction	0.10
Inflation rate	e_0	Fraction	0.05
Lifetime of PV module		Year	20
Lifetime of wind turbine		Year	20
Lifetime of inverter DC/AC		Year	10
Lifetime of controller		Year	10
Lifetime of submersible motor-pump unit		Year	10
Salvage value		DA[a]	10

[a] 1€ ≈ 100.00 DA.

Table 2
Capital costs of the two options of pumping water.

Pumping system	Capital cost (10^3 DA)[a]
Photovoltaic	2445
Wind turbine	1692

[a] 1€ ≈ 100.00 DA.

Table 3
Estimated costs per cubic meter of water produced by PV and wind turbine pumping systems – Site Adrar.

System	Costs of cubic meters of water produced (DA/m^3)
Photovoltaic	10.02
Wind turbine, hub height 18 m	9.98

equal to 1% of the total cost of equipment. The salvage value for all components of the two pumping systems is assumed to be equal to 0. Subsystems such as power conditioners (controller and inverter) and the motor-pump unit are replaced after a period of 10 years. Table 2 presents the approximate costs of investment of the two options of water pumping (PV and Wind turbine systems). It is to note that all equipments constituting the two options are currently imported and available in Algeria.

To preserve the quality of water for supplying the population with drinking water, the reservoir is chosen of cement type, elevated, and flared shape.

5.3. Comparison of cost per cubic meter of water produced by photovoltaic and wind turbine systems

One goal of this work given the characteristics of the different sites studied, is to determine what form of energy would be appropriate to whom and for what purposes. In other words, we will essentially identify suitable sites to operate an energy source compared to another while maintaining reliability to meet the need at lower cost. Given the potential wind energy available in the Adrar region, and in the light of this study, it appears to be more advantageous to use a wind turbine with hub height would be equal to 18 m. We note that this system can meet the needs requested, with greater reliability, better security and above all cheaper. Table 3

presents an estimate of costs per cubic meter of water produced by the photovoltaic and wind turbine systems.

We can notice for the site of Adrar, the pumping water wind turbine system has the lowest cost per cubic meter of water produced equal to 9.98 DA against 10.02 DA for the photovoltaic pumping system (optimal configuration).

6. Conclusions

Algeria and more particularly the Saharan regions enjoy a very considerable solar energy potential, on average only 5.5 kWh/m^2/day and reaching over 7 kWh/m^2/day especially during the summer. Demand for domestic water, irrigation of crops and watering of animals increase with the population growth. In the absence of surface water, groundwater is the only solution to meet those needs. Due to great depths, the means of animal and manual pumping are not appropriate. The alternative of mechanized water pumping is necessary in these conditions.

For several decades, the population uses the diesel genset to meet their need for electricity. Unfortunately, and given the various problems associated with using this type of equipment (fuel availability, emissions of CO_2, environmental pollution, soil and groundwater), suggests the use of renewable energy resources. Due to the nature of the country, solar energy and a lesser extent wind energy can be considered as a source of energy potentially available.

If the majority of the Sahara areas in Algeria have a relatively low wind energy potential, if not inappropriate to use this source of energy, Adrar region, on the contrary, and according to various studies [1,2,23], including the it possesses a potential for wind energy installation and use of low-power turbines.

Furthermore the high prices of PV systems, acts of vandalism having taken in this border region aiming at the photovoltaic installations, have undermined the sustainability and widespread use of these systems, even the people would not invest in this kind equipment for fear of being robbed. Mainly affected by these components are cheap photovoltaic modules for resale in neighboring countries.

In this work, we proposed an alternative solution, the wind pumping system at a certain height, capable of meeting the water needs of the population and that, with high reliability and most importantly better security. Also, we have shown the viability of a pumping system by a wind turbine compared to a PV system.

The cost per cubic meter of water produced by the wind pump system is cheaper than that produced by the PV system. The wind pumping system in the Adrar region, despite the high solar energy potential, may be required under current conditions, and may even experience a large-scale use, as the availability and particularly governmental aid exist.

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References

[1] Kasbadji Merzouk N. Wind Energy Potential of Algeria. International Journal of Renewable Energy 2000;21:553–62.
[2] Kasbadji Merzouk N, Merzouk M. Useful wind powers machine estimation, application to water pumping systems in South of Algeria. In: 9 International Congress on Mechaniszation and Energy Agriculture, 27 International Conference on CIGR. 2005.
[3] Daaou Nedjari H, Haddouche S et Kasbadji Merzouk N. Utilisation de l'énergie éolienne pour le pompage de l'eau dans les hauts plateaux, JITH2005, Tanger, Maroc; novembre 2005.
[4] Kedaid FZ. Les perspectives d'utilisation de l'énergie géothermique au sud de l'Algérie. Bulletin des Energies Renouvelables, No 5; Juin 2004.
[5] Fekraoui A, et Kedaid FZ. Geothermal resources and uses in Algeria: a country updata report. In: Proceedings World Geothermal Congress 2005. 2005.
[6] Celik AN. Energy output estimation for small-scale wind power generators using weibull-representative wind data. Journal of Wind Engineering and Industrial Aerodynamics 2003;91:693–707.
[7] Justis CG. Wind and wind system performance. Philadelphia: Franklin Institute Press; 1978.
[8] Hammouche R. Atlas Vent de l'Algérie. Office National de la Météorologie 1991.
[9] Justus CG, Hargraves WR, Yalcin A. Nationwide assessment of potential output from wind-powered generators. Journal of Applied Meteorology 1978;15(7):673–8.
[10] Justus CG. Vent et performances des éoliennes. Paris: Ed SCM; 1978.
[11] Guerri O, Ameur K, Kaabache K, Moussa S et Harhad A. Pompage de l'Eau à l'Aide d'un Aérogénérateur Utilisation de L'Energie Eolienne pour le Pompage de l'Eau dans la Région d'Adrar. Rev. Energ Ren 2002;Zones Arides:63–68.
[12] Mikhaeil AS, Justus CG. Comparison of height extrapolation models and sensitivity analysis. Wind Engineering 1981;5(2):91–106.
[13] Mikhaeil AS. Height extrapolation of wind data. Journal of Solar Energy Engineering 1985;107:10–4.
[14] Yang H, Zhou W, Lou C. Optimal design and techno-economic analysis of a hybrid solar–wind power generation system. Applied Energy 2009;86(2):163–9.
[15] Yang H, Lu L, Zhou W. A novel optimization sizing model for hybrid solar–wind power generation system. Solar Energy 2007;81(1):76–84.
[16] Purohit P. Financial evaluation of renewable energy technologies for irrigation water pumping in India. Energy Policy 2007;35(6):3134–44.
[17] Thomas MG. Water pumping: the solar alternative. SAND8T-0804. Albuquerque, NM: Sandia National Laboratories Photovoltaic Systems Design Center; 1993.
[18] Odeh I, Mahmoud M. Field results of photovoltaic water pumping systems. Applied Solar Energy 1995;31(3):20–9.
[19] Brandemuehl MJ, Beckman WA. Economic evaluation and optimization of solar heating systems. Solar Energy 1979;23:1–10.
[20] Chandrasekar B, Kandpal TC. Effect of financial and fiscal incentives on the effective capital cost of solar energy technologies to the user. Solar Energy 2005;78:147–56.
[21] Hamidat A. Simulation of the performance and cost calculations of the surface pump. Renewable Energy 1999;18:383–92.
[22] Bouzidi B, Haddadi M, Belmokhtar O. Assessment of a photovoltaic pumping system in the area of the Algerian Sahara. Renewable and Sustainable Energy Reviews 2009;13(4):879–86.
[23] Bouzidi B. Contribution to the improvement of the water pumping by renewable energies. Doctoral Thesis. Polytechnic School – Algiers; December 2010.
[24] Rajendra Prasad A, Natarajan E. Optimization of integrated PV/wind power generation systems with battery storage. Energy 2006;31:1943–54.
[25] Ahmed Shata AS, Hanitsch R. Evaluation of wind energy potential and electricity generation on the coast of Mediterranean Sea in Egypt. Renewable Energy 2006;31:1183–202.
[26] Groumpos PP, Papageorgiou G. An optimal sizing method for stand-alone PV power systems. Solar energy 1987;38(5):341–51.
[27] Nguyen QK. Alternatives to grid extension for rural electrification: decentralized renewable energy technologies in Vietnam. Energy Policy 2007;35:2579–89.
[28] Bhuiyan MMH, Asgar MA, Mazumder RK, Hussain M. Economic evaluation of a stand-alone residential PV power system in Bangladesh. Renewable energy 2000;21:403–10.